Recent Progress in Studying AGN Outflows

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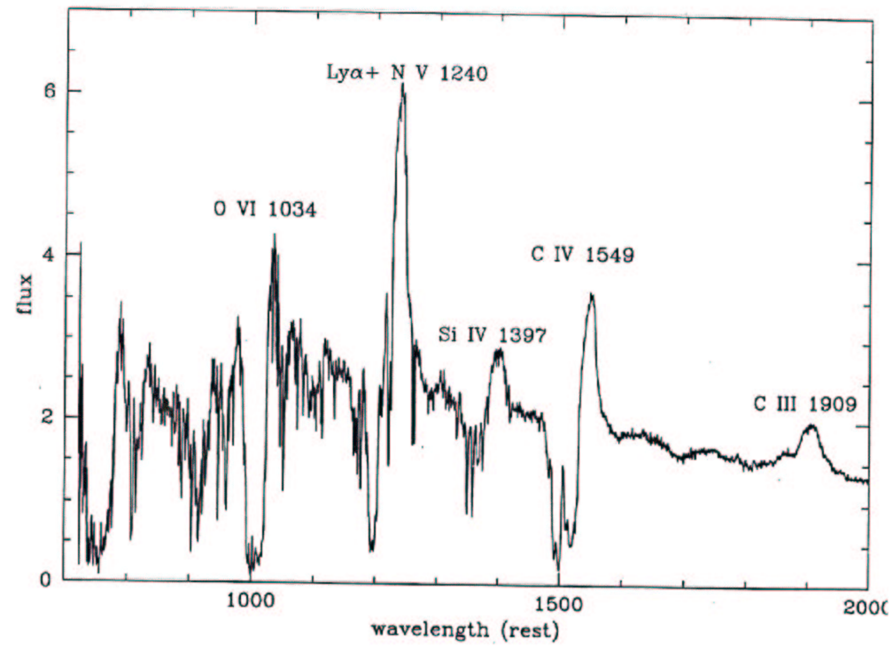
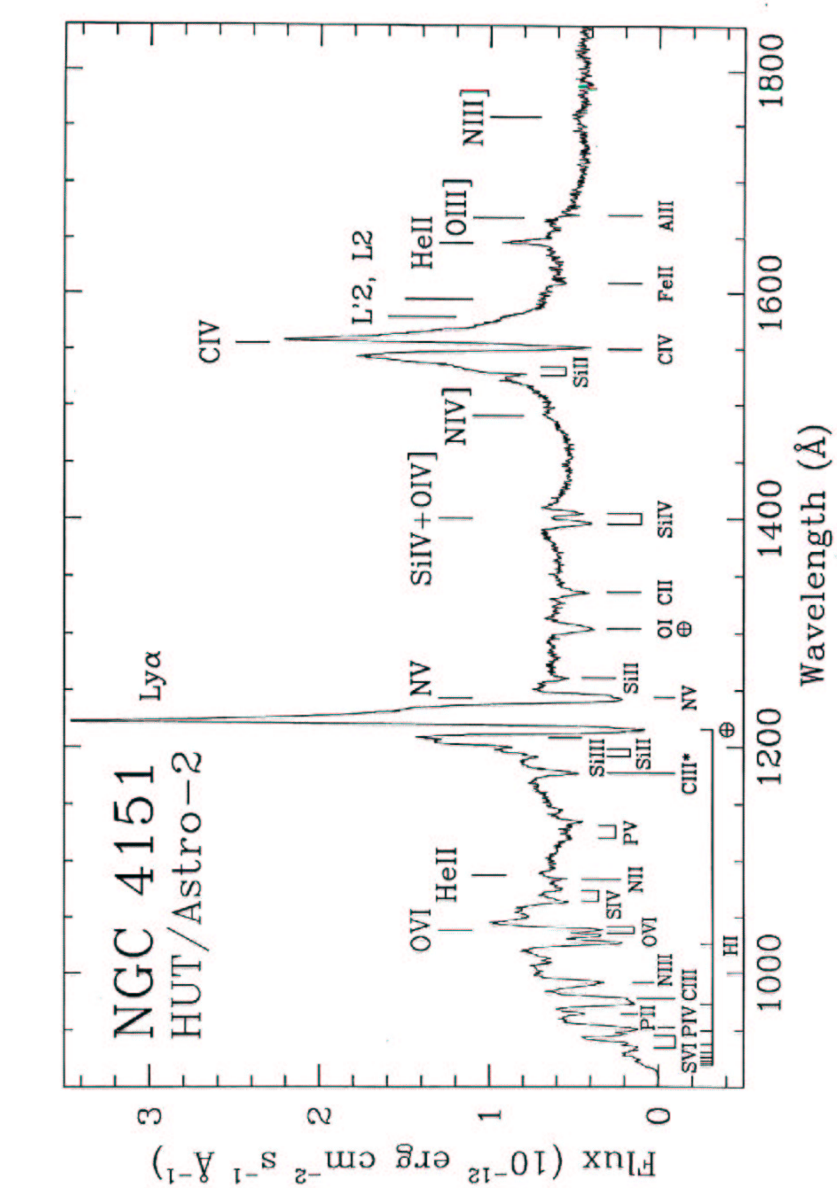
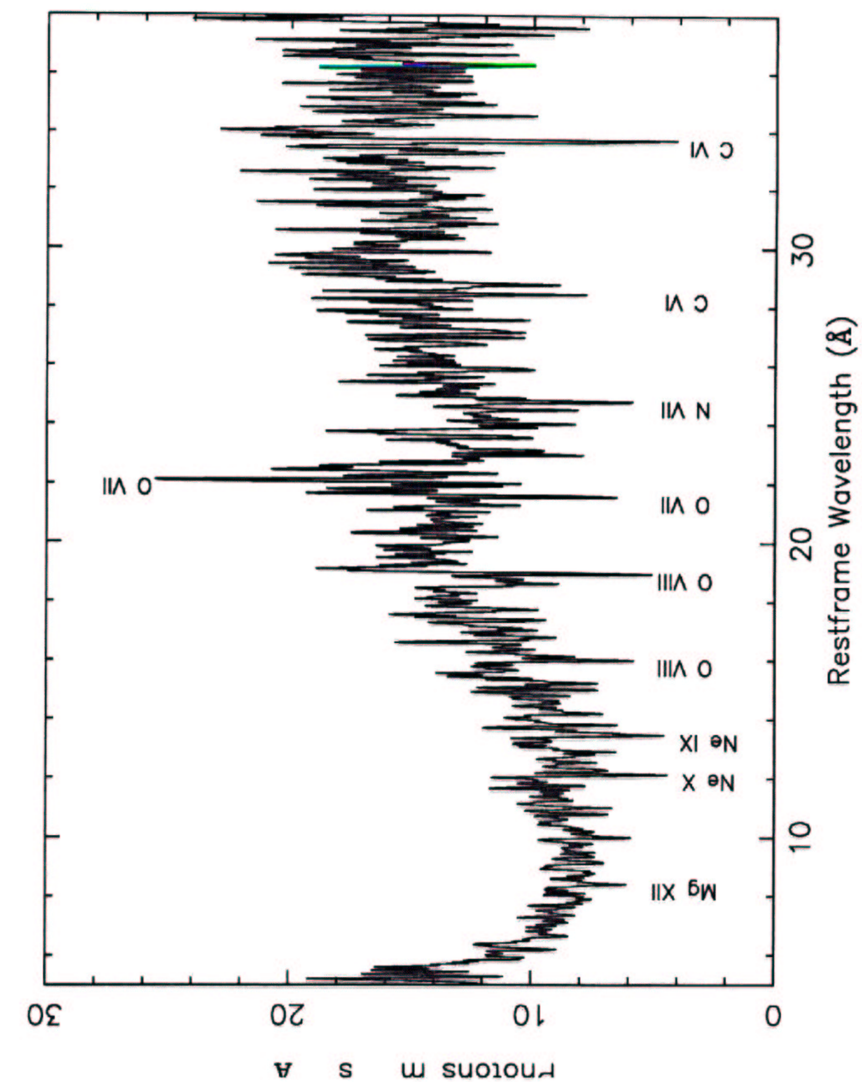
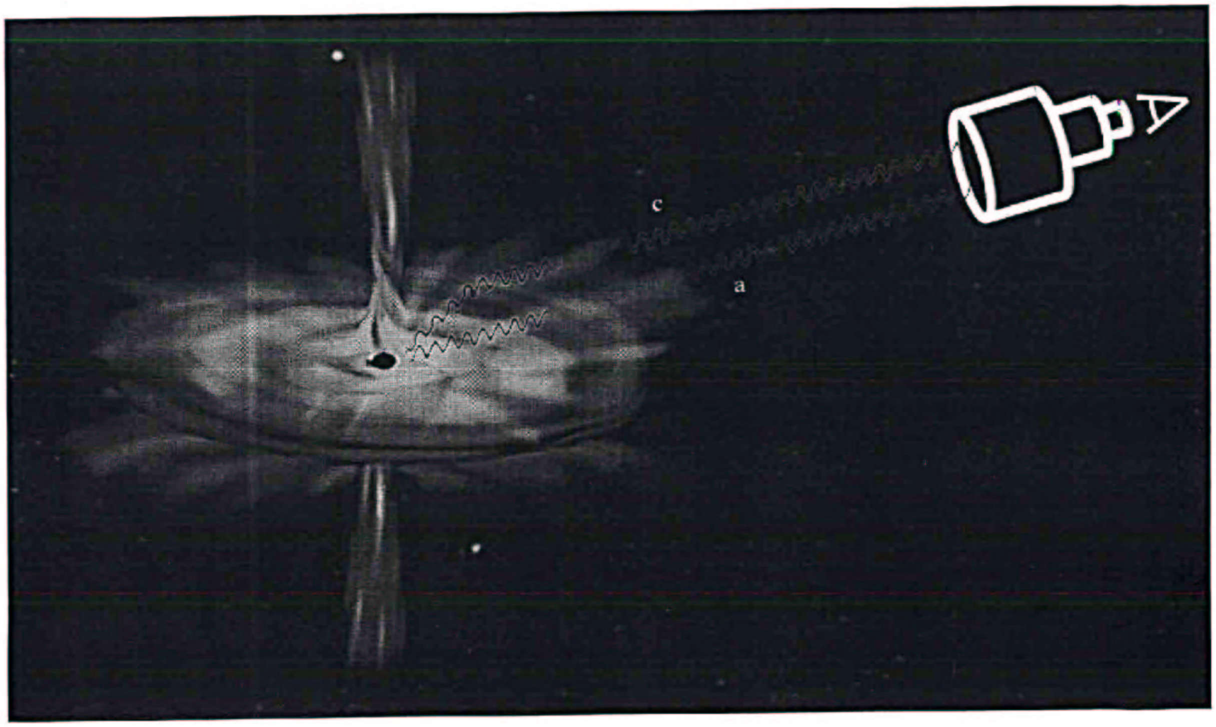
- Introduction to AGN Outflows
- Optical: Keck high resolution spectroscopy, surveys
- UV: HST and FUSE high resolution spectroscopy
- X-ray: Chandra and XMM "high resolution spectroscopy"
- Future Directions



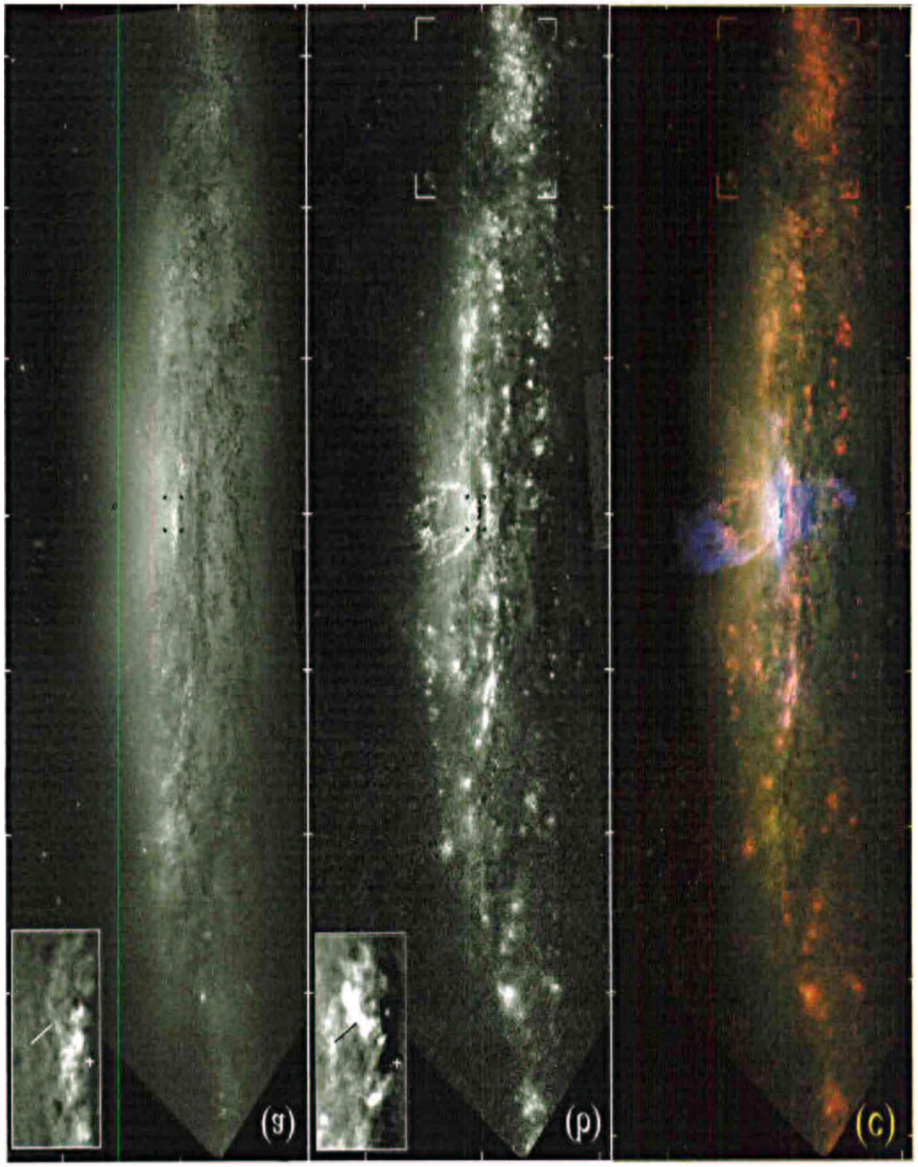

NGC 4151
HUT/Astro-2
Lyα
CIV
L'2, L2
HeII
[OIII]
NIII]
NIV]
SiIV+OIV]
NV
OVI
Wavelength (Å)
Flux (10^-12 erg cm^-2 s^-1 Å^-1)

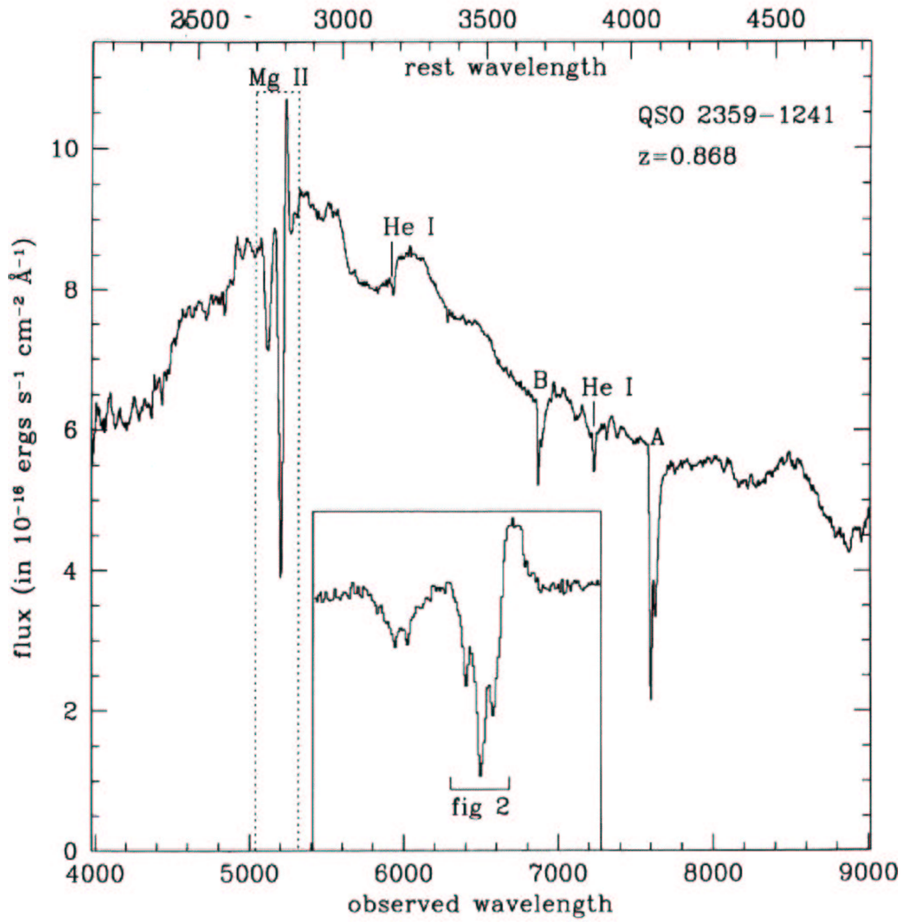

C VI
N VII
O VII
O VIII
Ne IX
Ne X
Mg XII
Restframe Wavelength (Å)

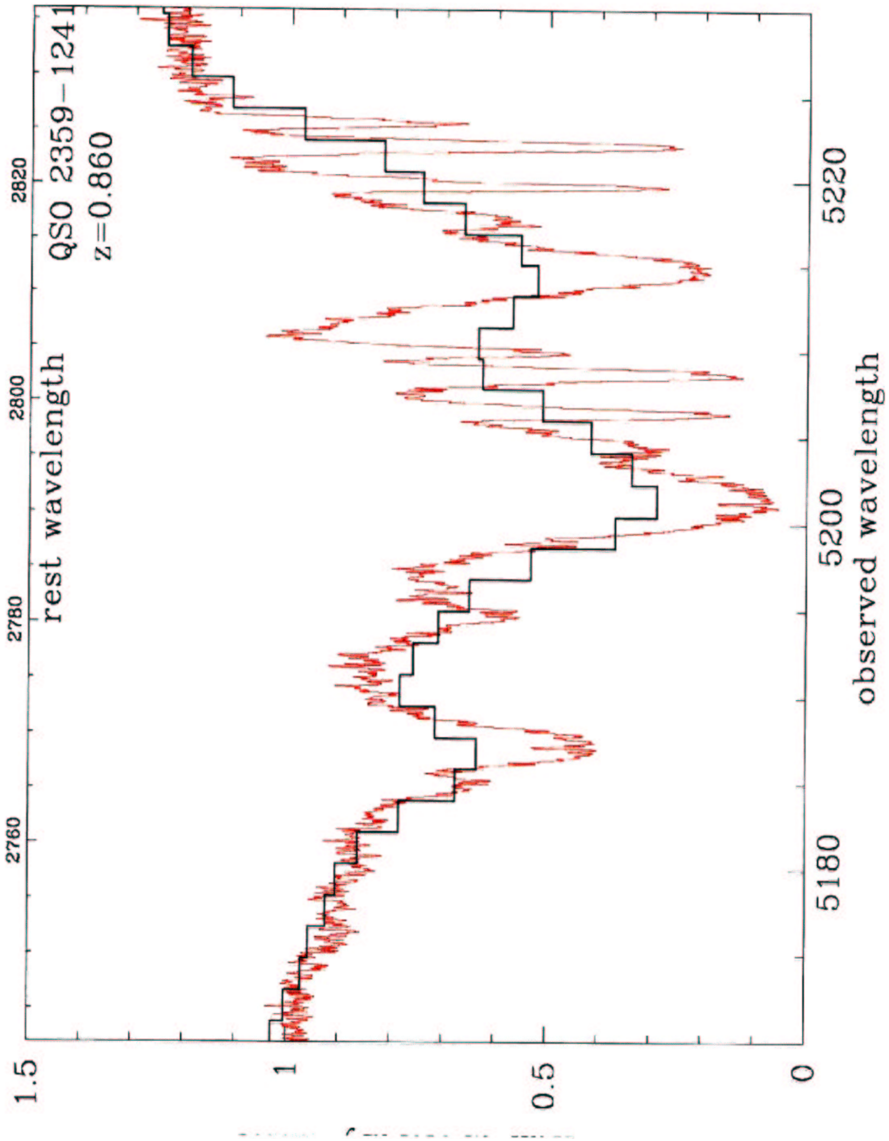


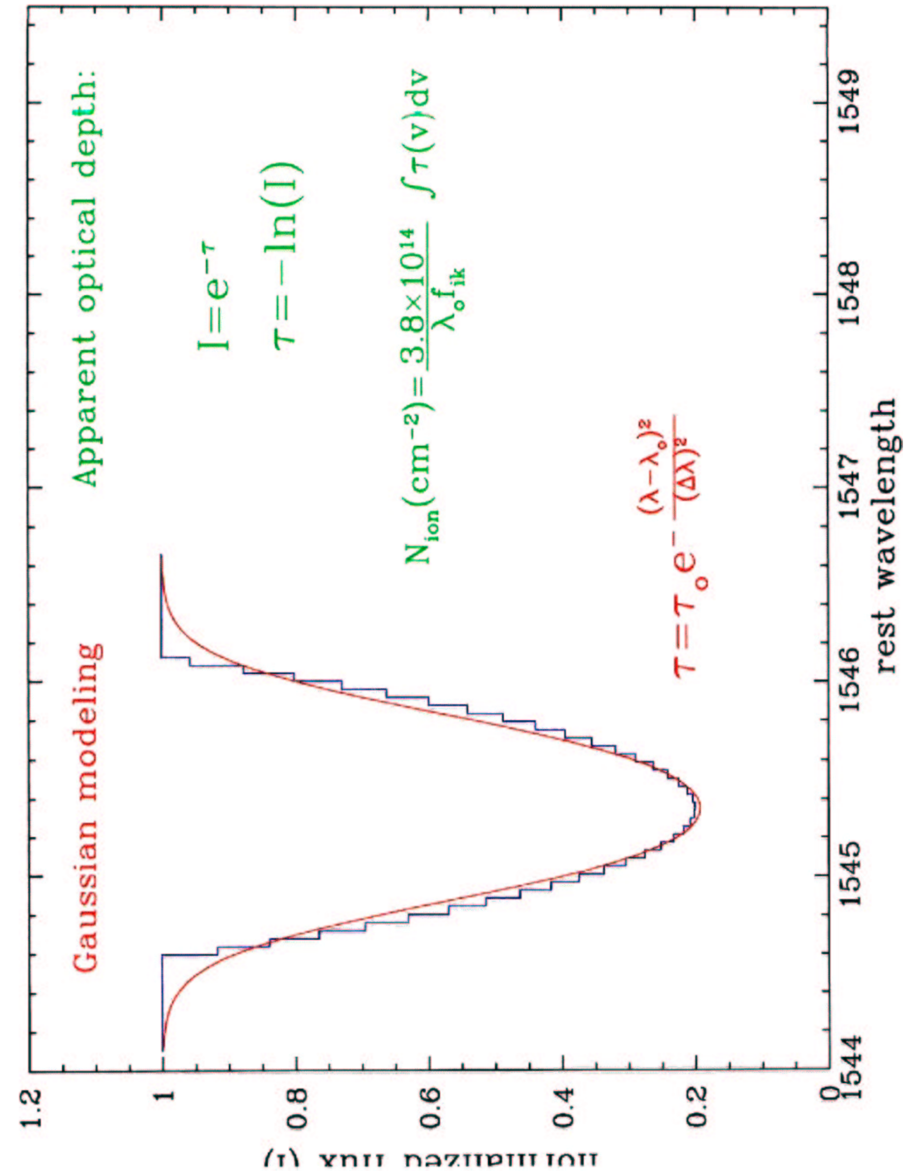
Fundamental questions about AGN outflows:

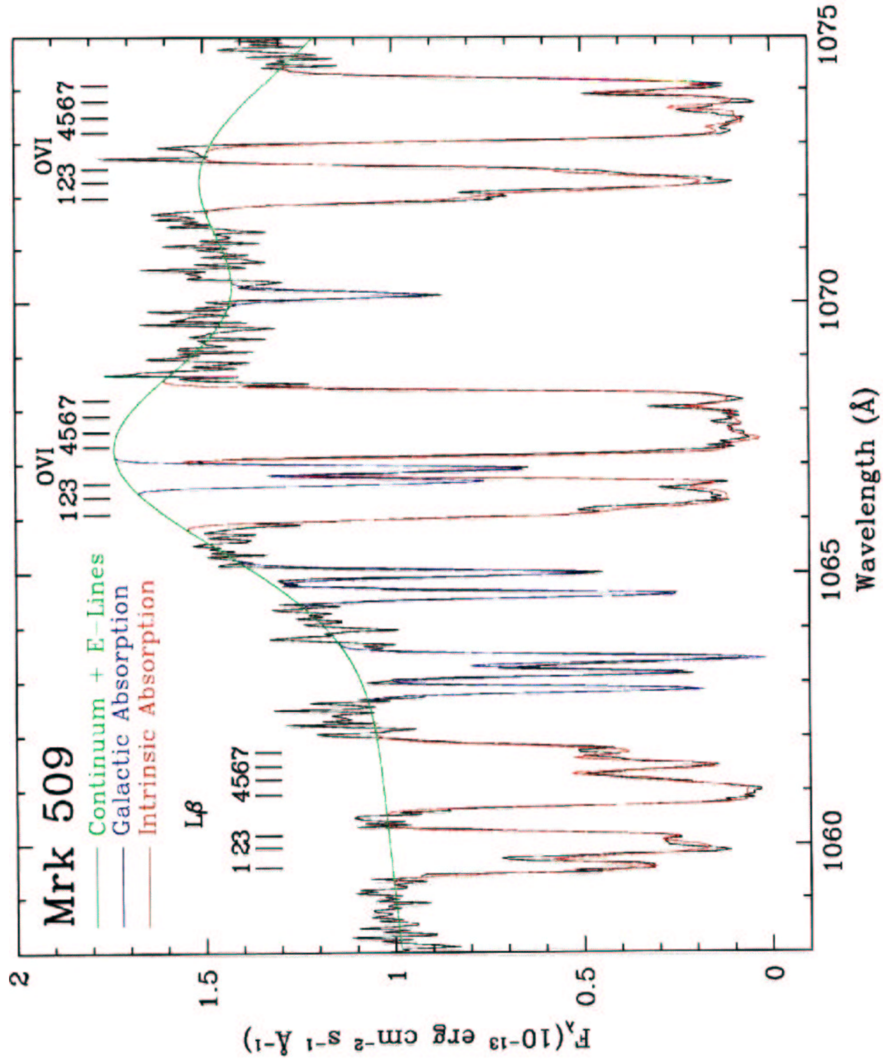
- What is the relationship between the UV and X-ray warm absorbers?
- What are the ionization equilibrium and abundances?
- Where is the outflow, and what accelerates it?
- How important is the outflow in AGN and host galaxy evolution?

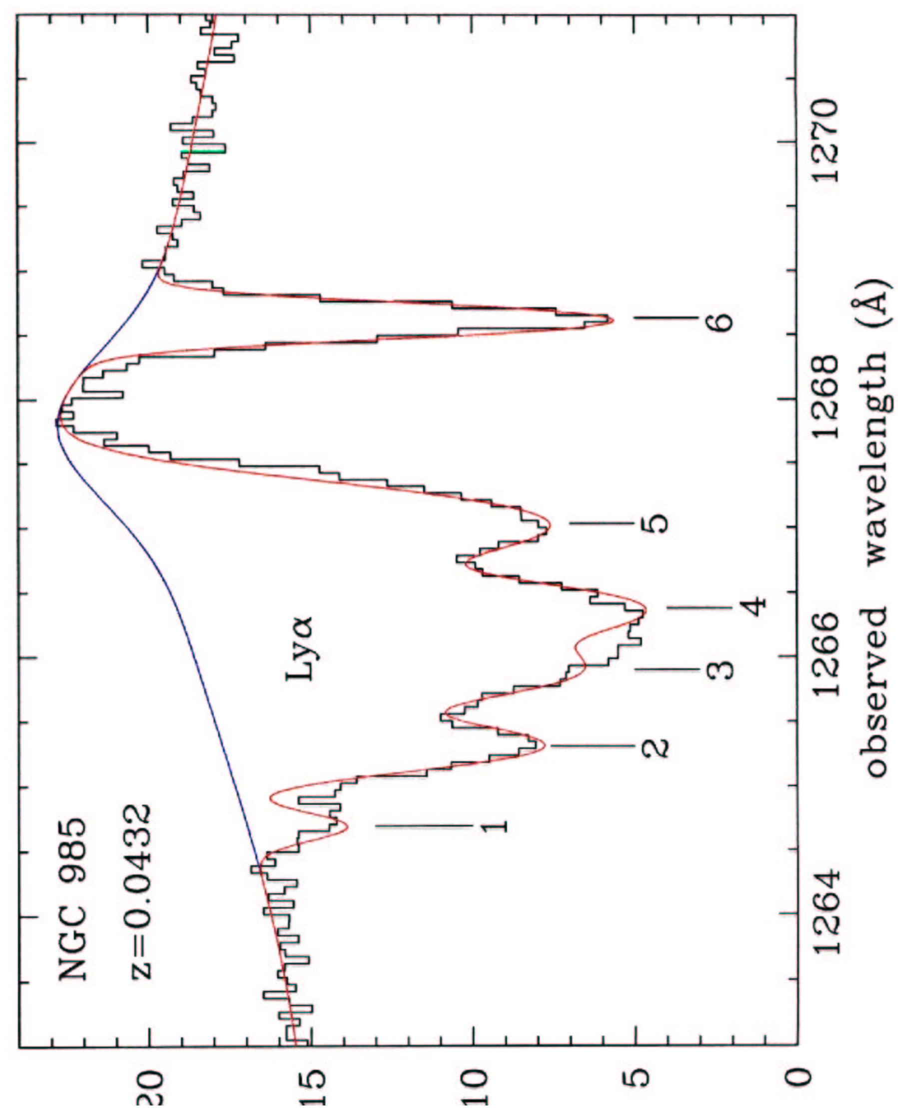

(g)
(p)
(c)

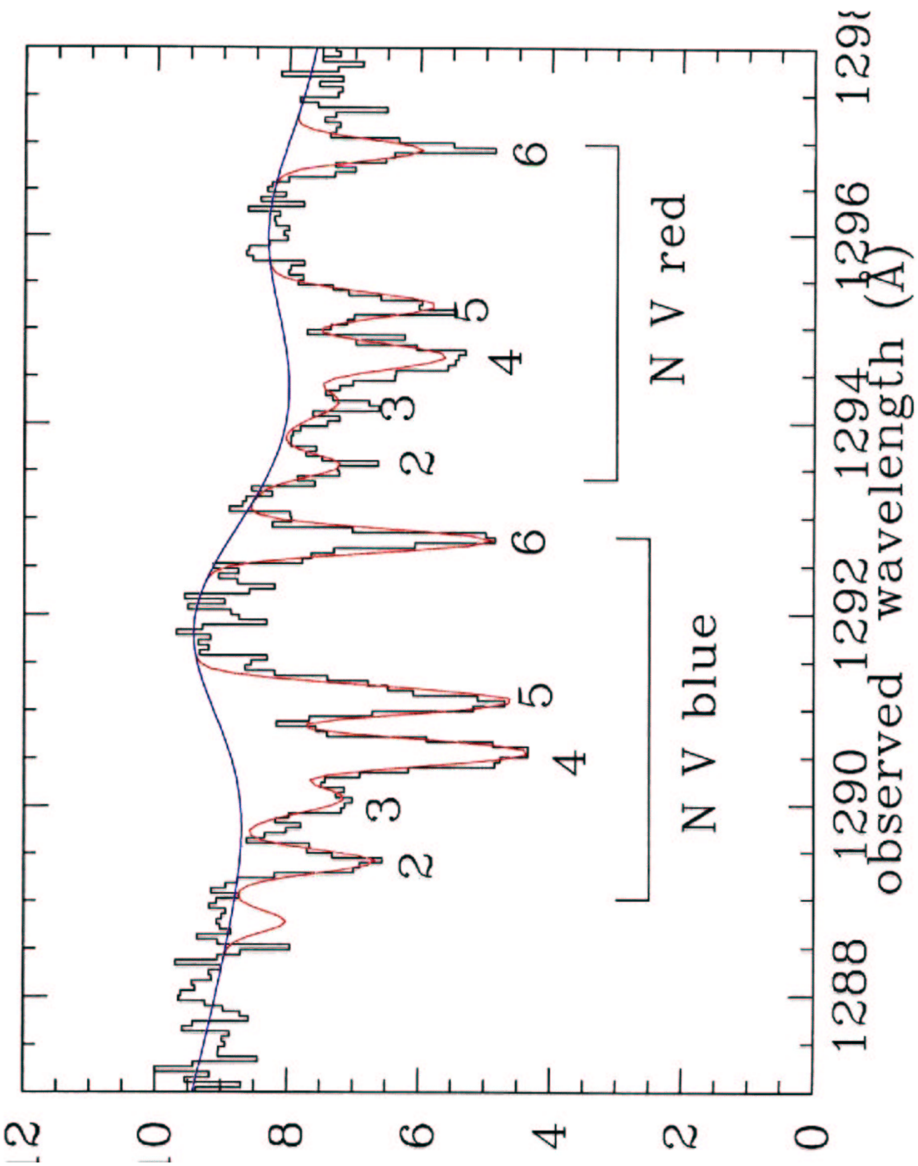

2500
3000
3500
4000
4500
rest wavelength
Mg II
QSO 2359−1241
z=0.868
He I
B
He I
A
fig 2
flux (in 10^{-16} ergs s^{-1} cm^{-2} $Å^{-1}$)
0
2
4
6
8
10
4000
5000
6000
7000
8000
9000
observed wavelength

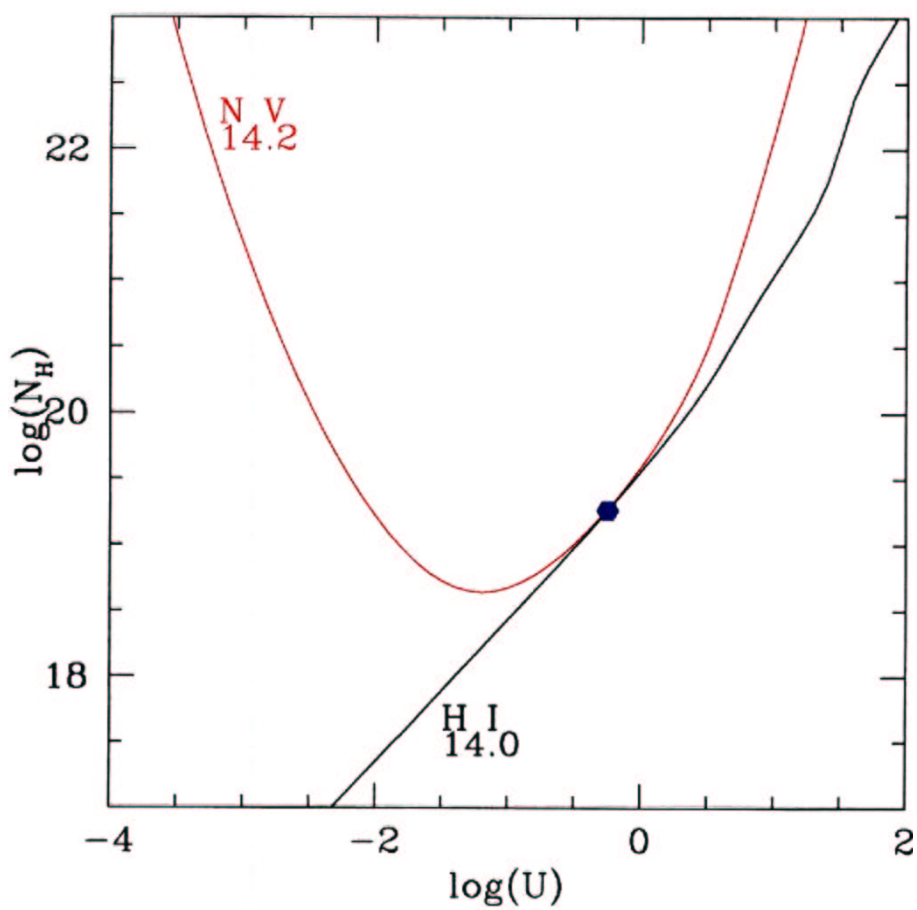

QSO 2359−1241
z=0.860
rest wavelength
2760
2780
2800
2820
observed wavelength
5180
5200
5220
1.5
1
0.5
0

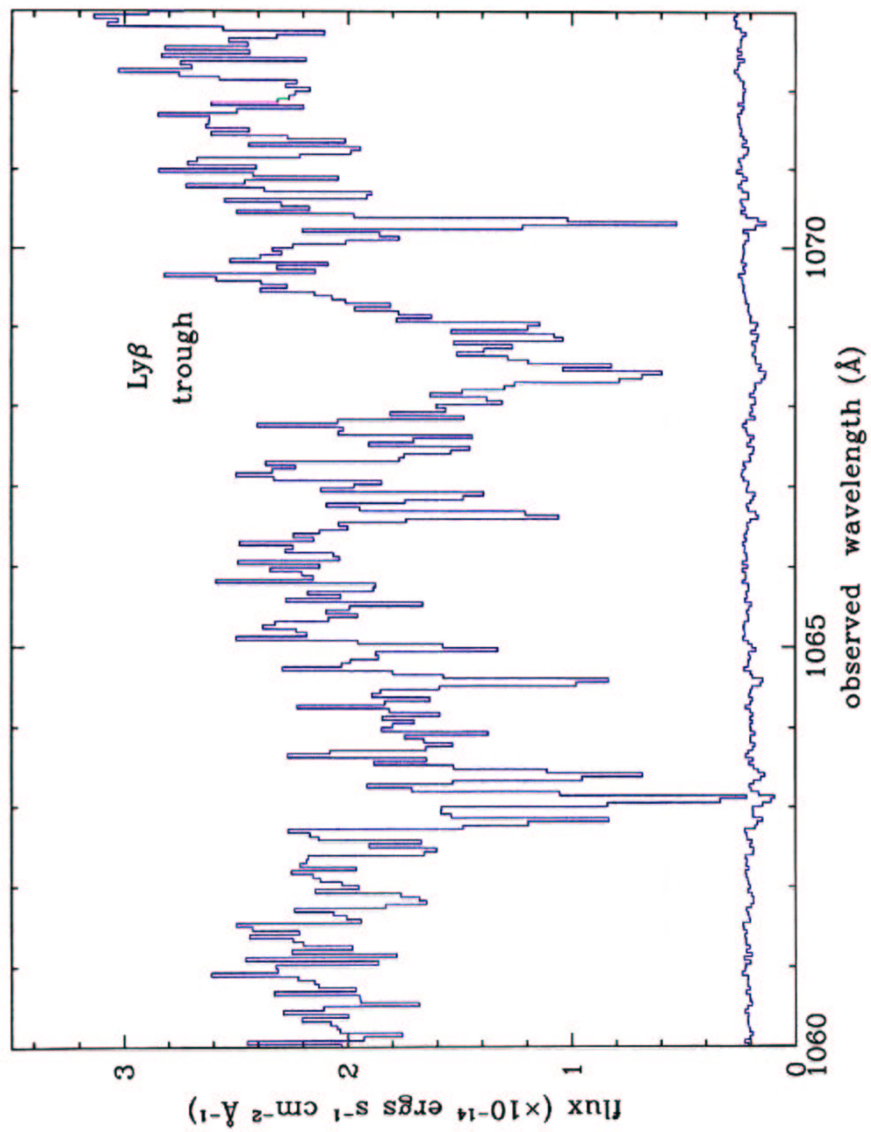

Apparent optical depth:
$I=e^{-\tau}$
$\tau=-\ln(I)$
$N_{ion}(cm^{-2})=\frac{3.8\times10^{14}}{\lambda_o f_{ik}}\int\tau(v)dv$
Gaussian modeling
$\tau=\tau_o e^{-\frac{(\lambda-\lambda_o)^2}{(\Delta\lambda)^2}}$
rest wavelength
1544
1545
1546
1547
1548
1549
1.2
1
0.8
0.6
0.4
0.2
0

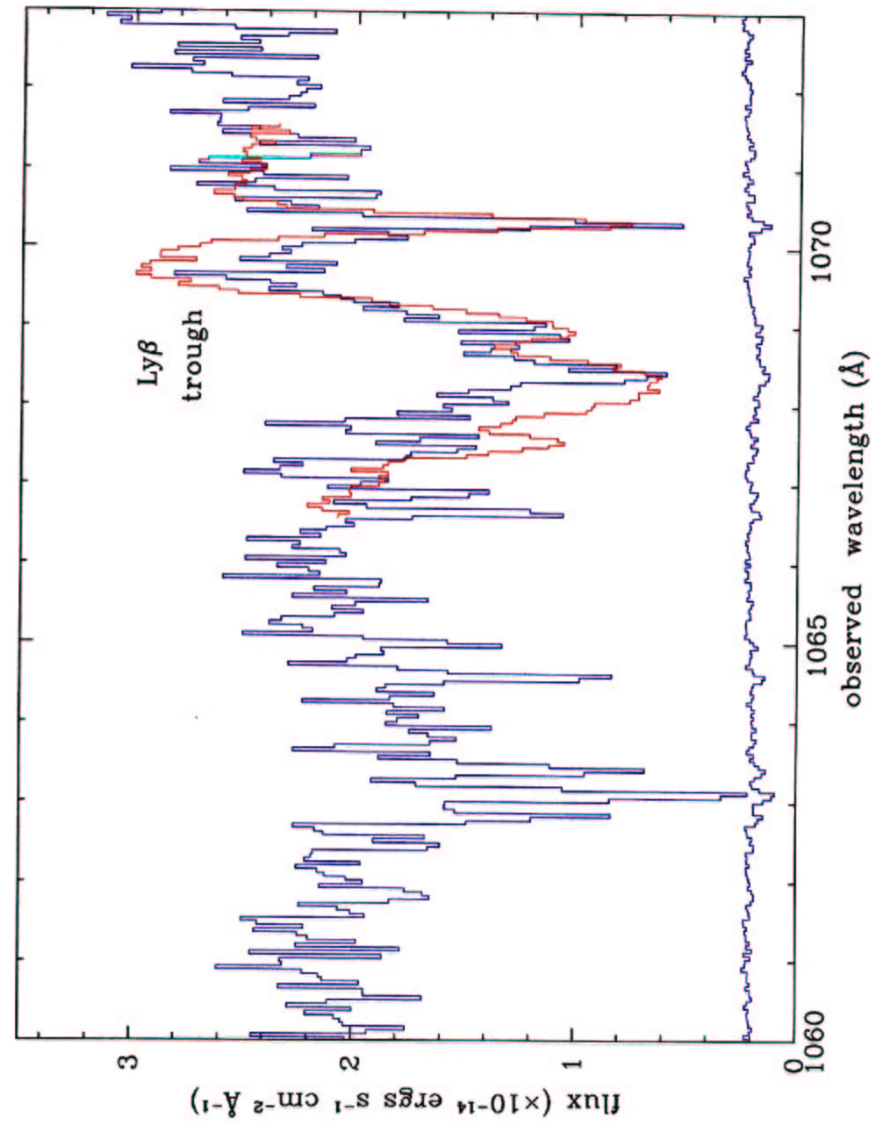

Mrk 509
Continuum + E–Lines
Galactic Absorption
Intrinsic Absorption
Lβ
1 23 4567
OVI
123 4567
OVI
123 4567
1060
1065
1070
1075
Wavelength (Å)
0
0.5
1
1.5
2
$F_\lambda(10^{-13}$ erg cm^{-2} s^{-1} Å$^{-1})$

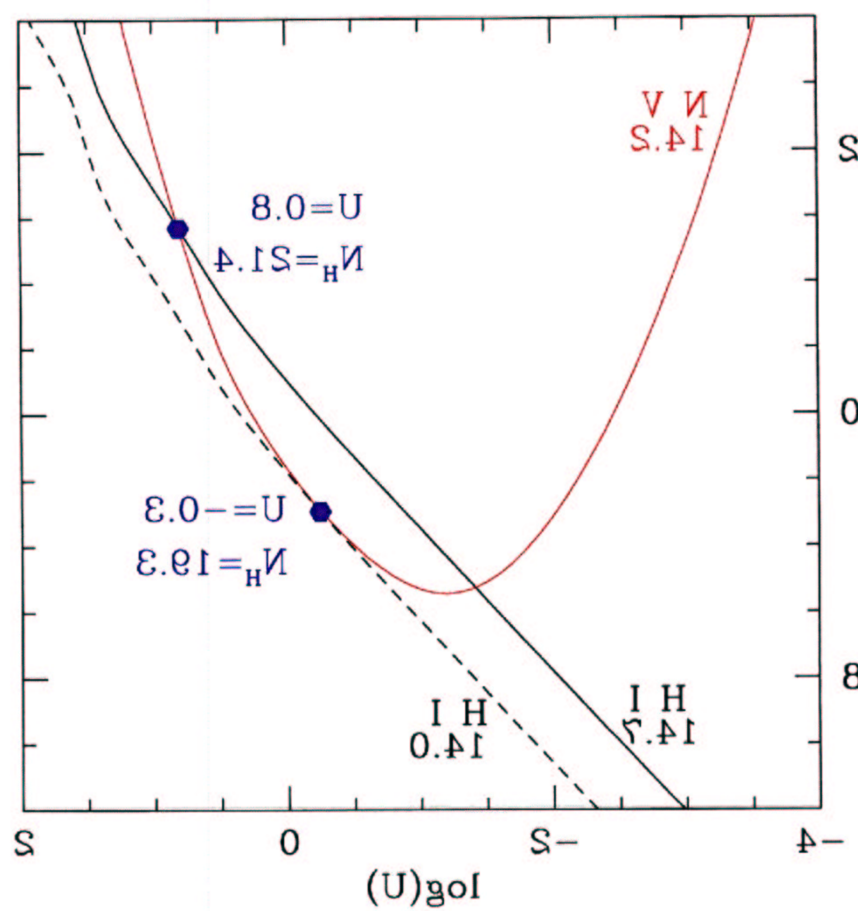

NGC 985
z=0.0432
Lyα
1
2
3
4
5
6
1264
1266
1268
1270
observed wavelength (Å)
0
5
10
15
20


N V red
N V blue
observed wavelength (Å)

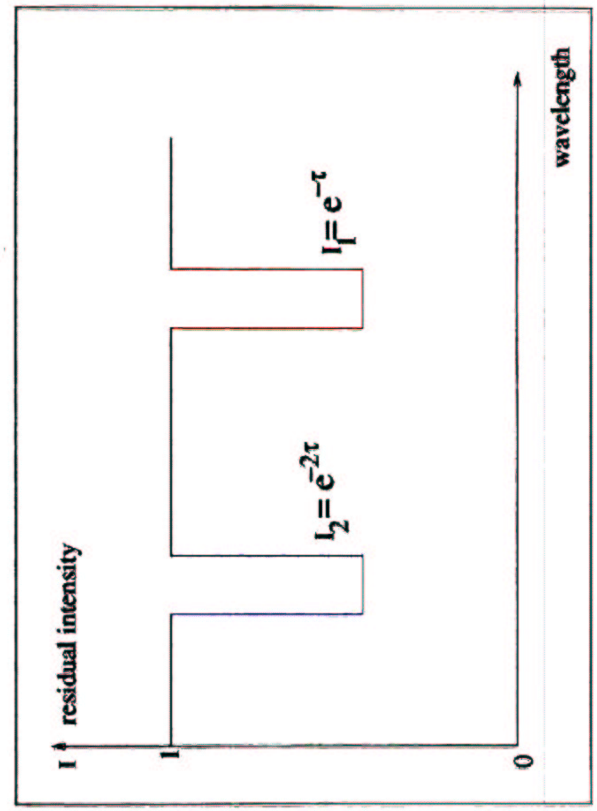

N V
14.2
H I
14.0
log(U)
log(N_H)


Lyβ
trough
flux (×10⁻¹⁴ ergs s⁻¹ cm⁻² Å⁻¹)
observed wavelength (Å)
0
1
2
3
1060
1065
1070

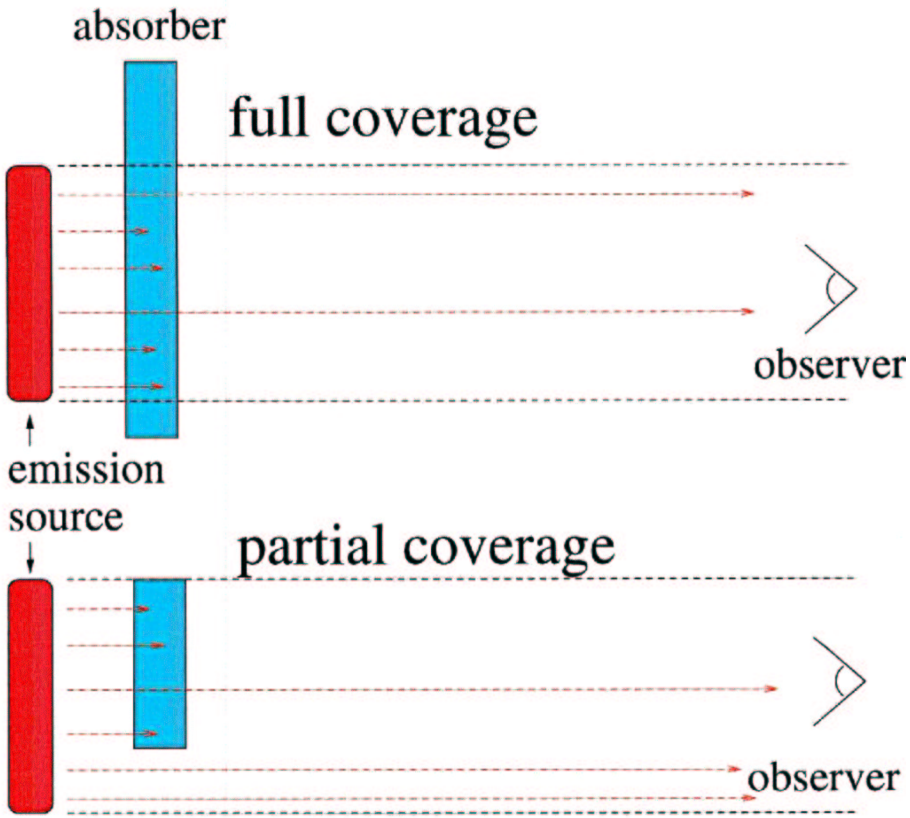

Lyβ
trough
flux (×10⁻¹⁴ ergs s⁻¹ cm⁻² Å⁻¹)
observed wavelength (Å)
0
1
2
3
1060
1065
1070

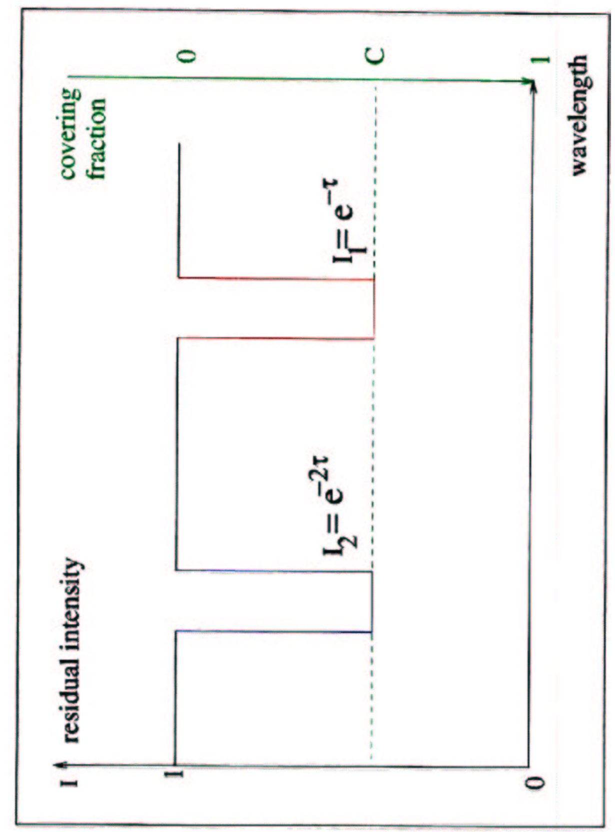


log(U)
log(N_H)
N V
14.2
U=0.8
N_H=21.4
U=−0.3
N_H=19.3
H I
14.0
H I
14.7



residual intensity
wavelength
I_1=e^-τ
I_2=e^-2τ


absorber
full coverage
observer
emission
source
partial coverage
observer


covering
fraction
wavelength
$I_1 = e^{-\tau}$
$I_2 = e^{-2\tau}$
residual intensity

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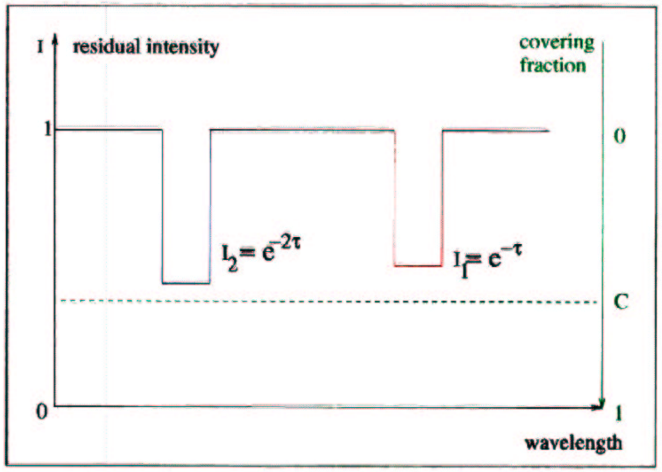
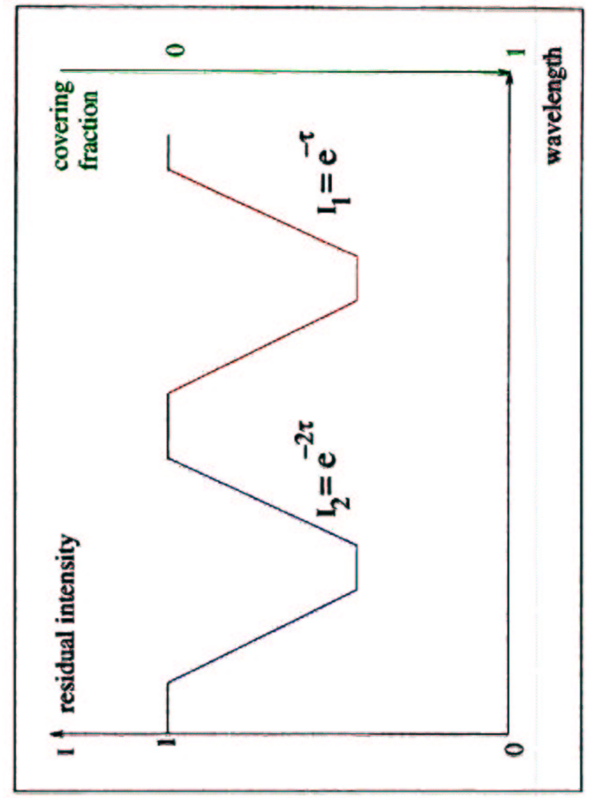


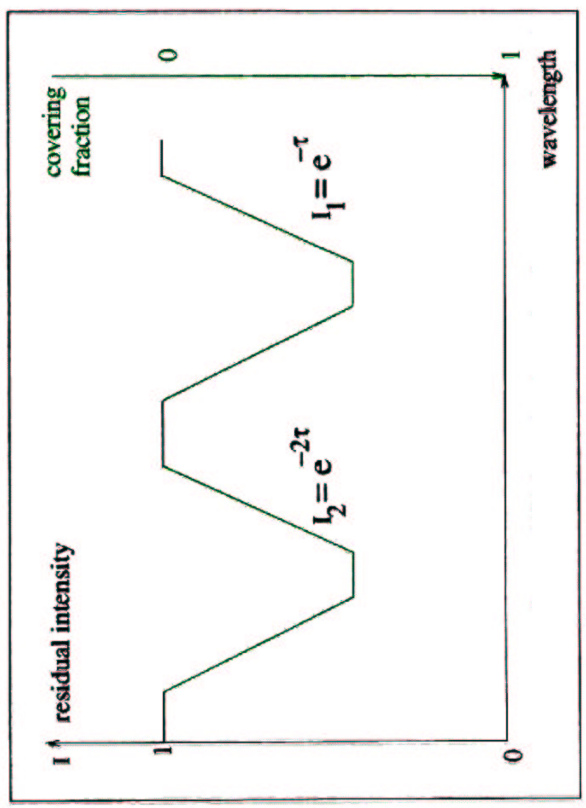
$$I_1(v) - (1 - C(v)) = C(v)e^{-\tau(v)} \quad (1)$$

$$I_2(v) - (1 - C(v)) = C(v)e^{-2\tau(v)}, \quad (2)$$

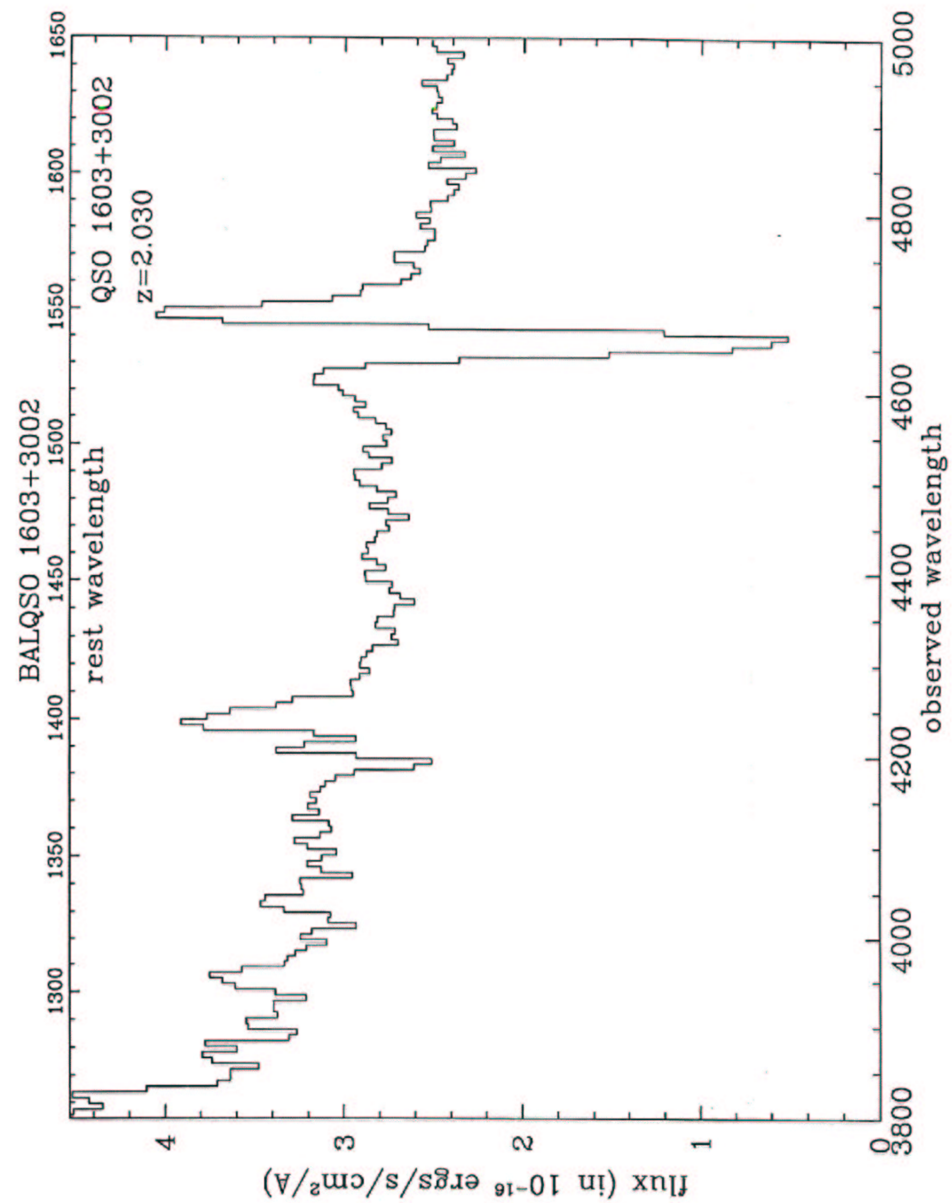
$$C(v) = \frac{I_1(v)^2 - 2I_1(v) + 1}{I_2(v) - 2I_1(v) + 1}, \quad (3)$$

$$\tau(v) = -\ln\left(\frac{I_1(v) - [1 - C(v)]}{C(v)}\right) = -\ln\left(\frac{I_1(v) - I_2(v)}{1 - I_1(v)}\right), \quad (4)$$

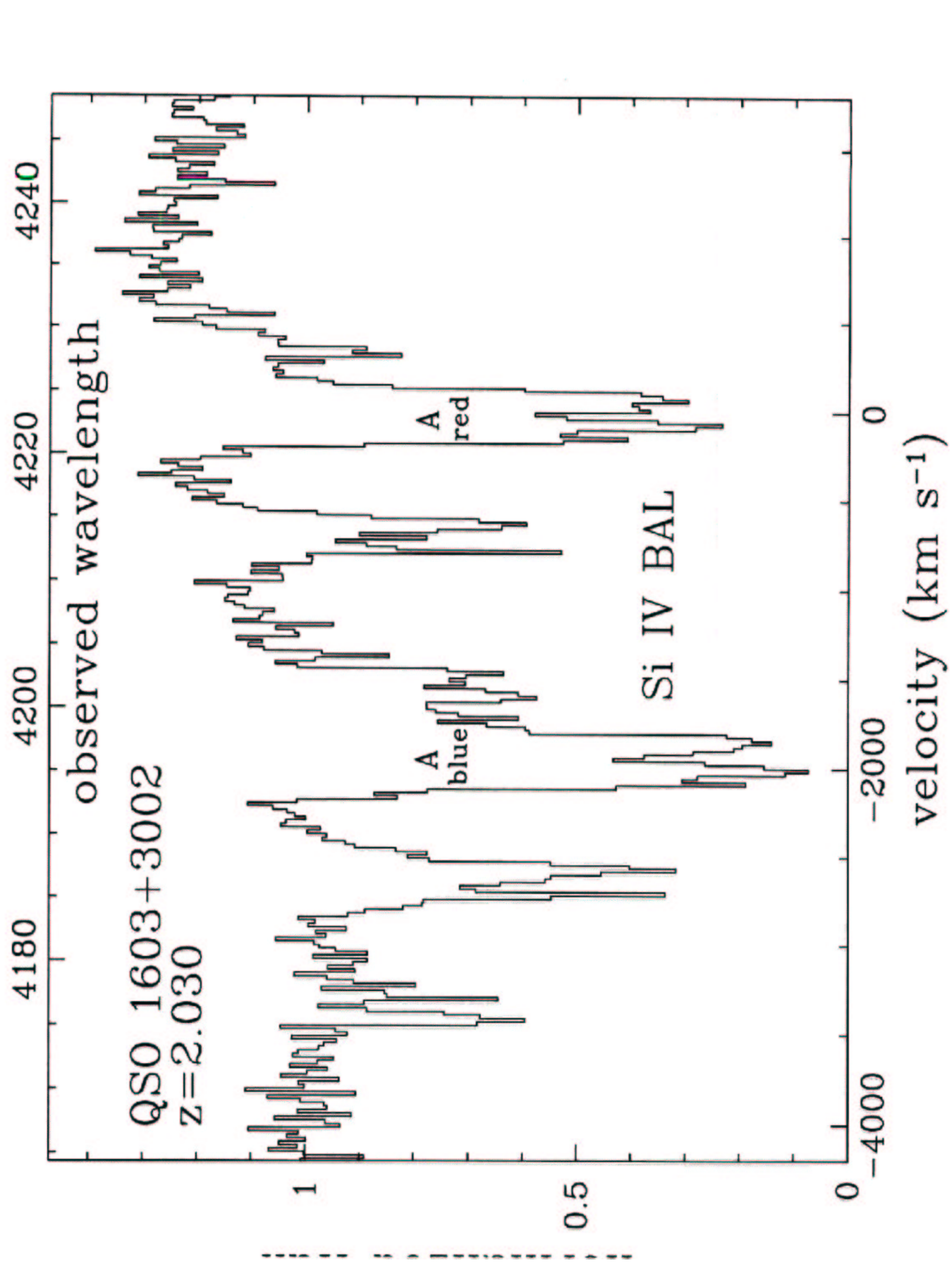


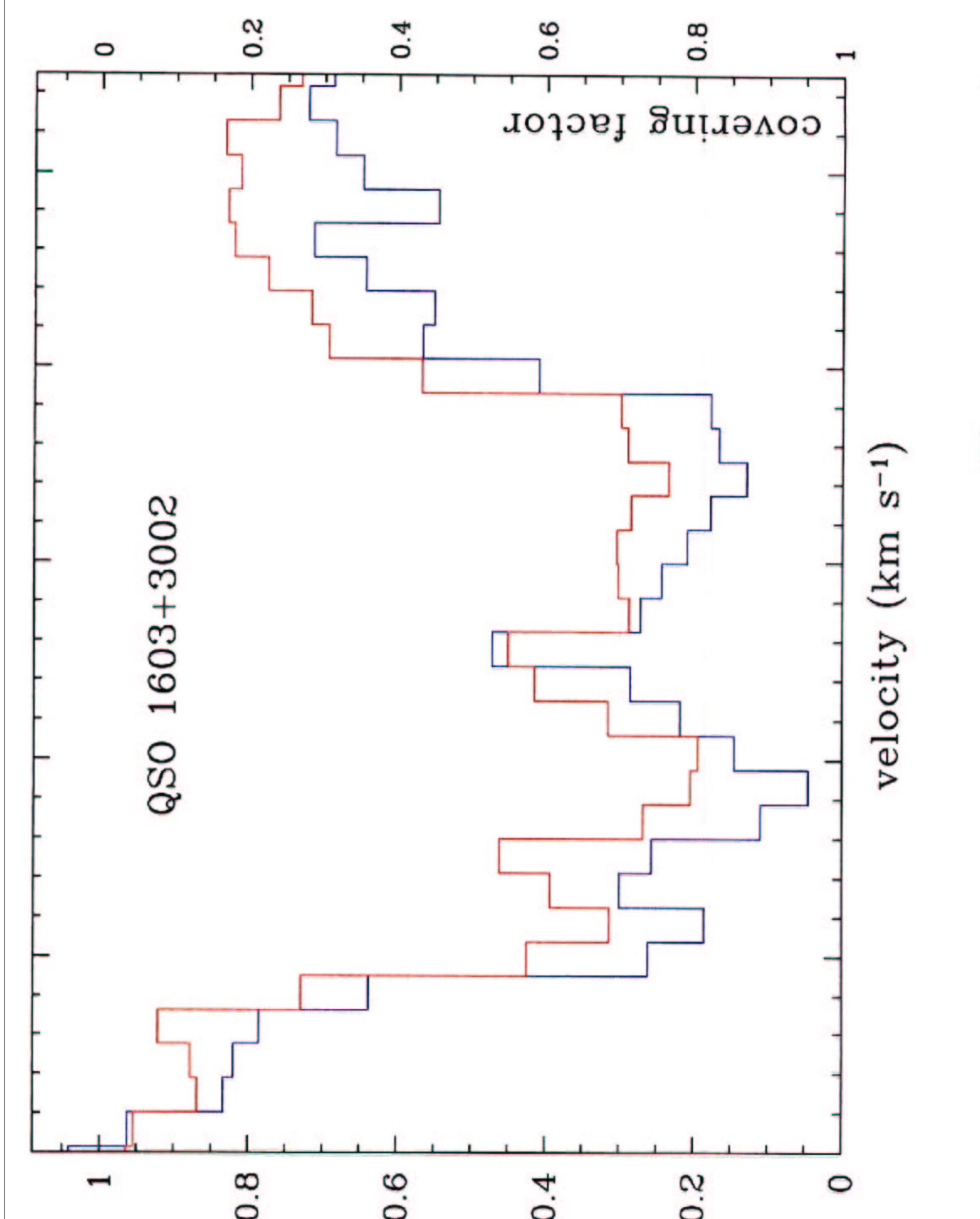


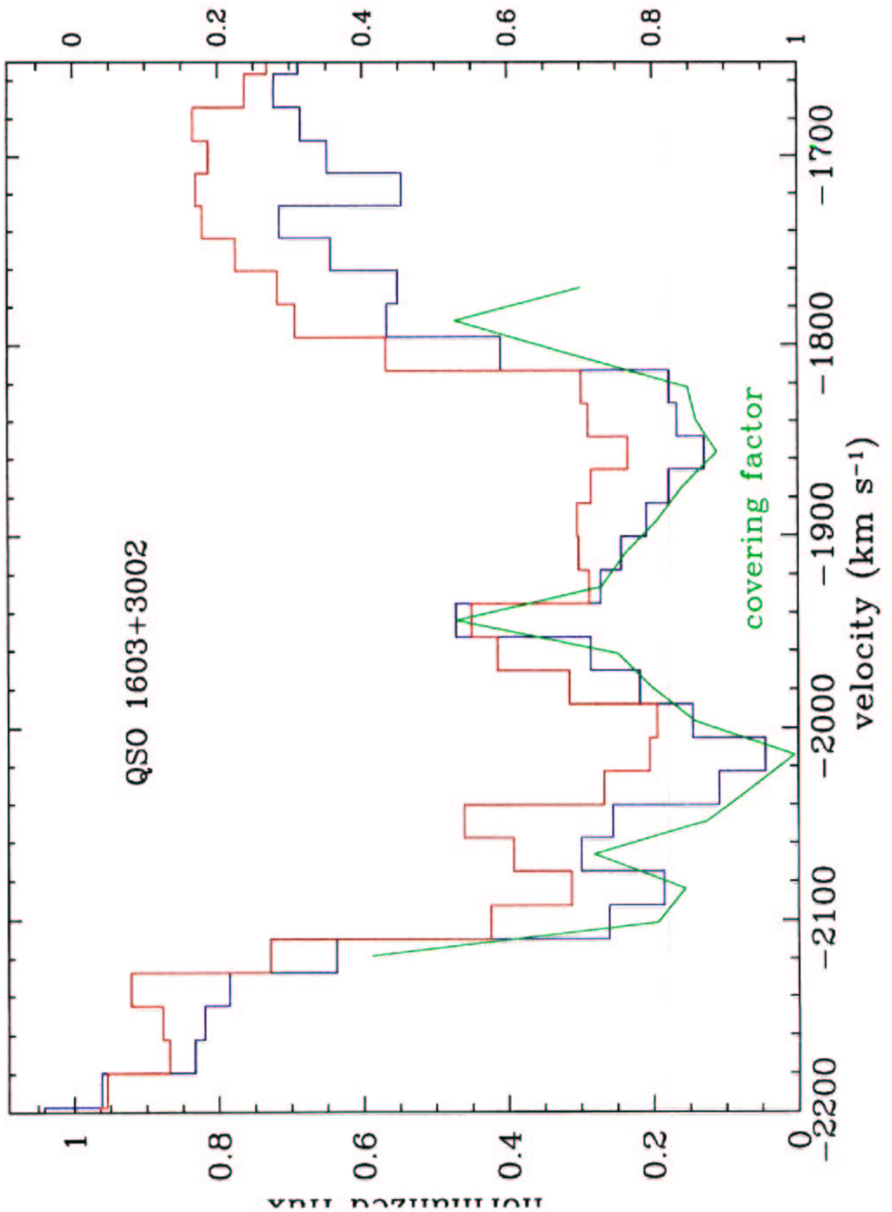
residual intensity
covering fraction
wavelength
$I_1 = e^{-\tau}$
$I_2 = e^{-2\tau}$

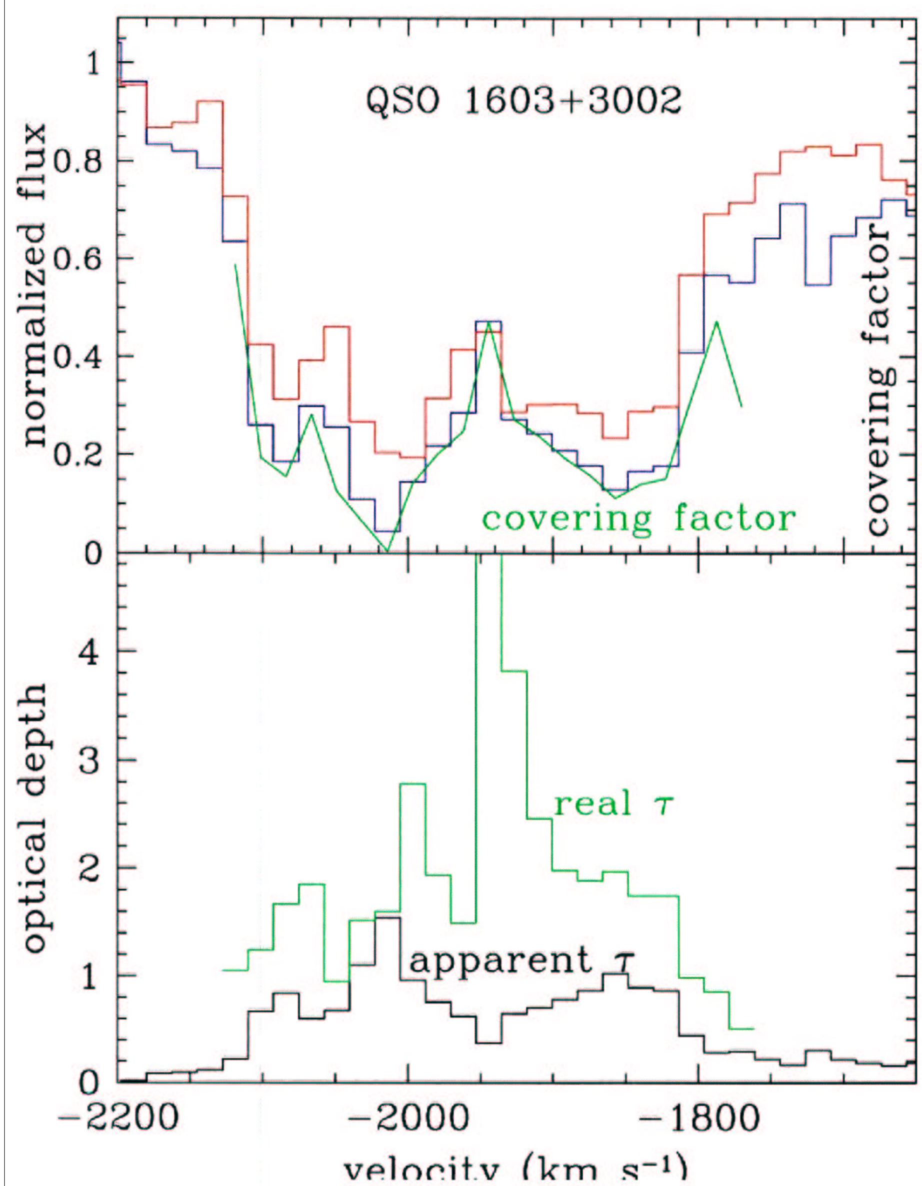


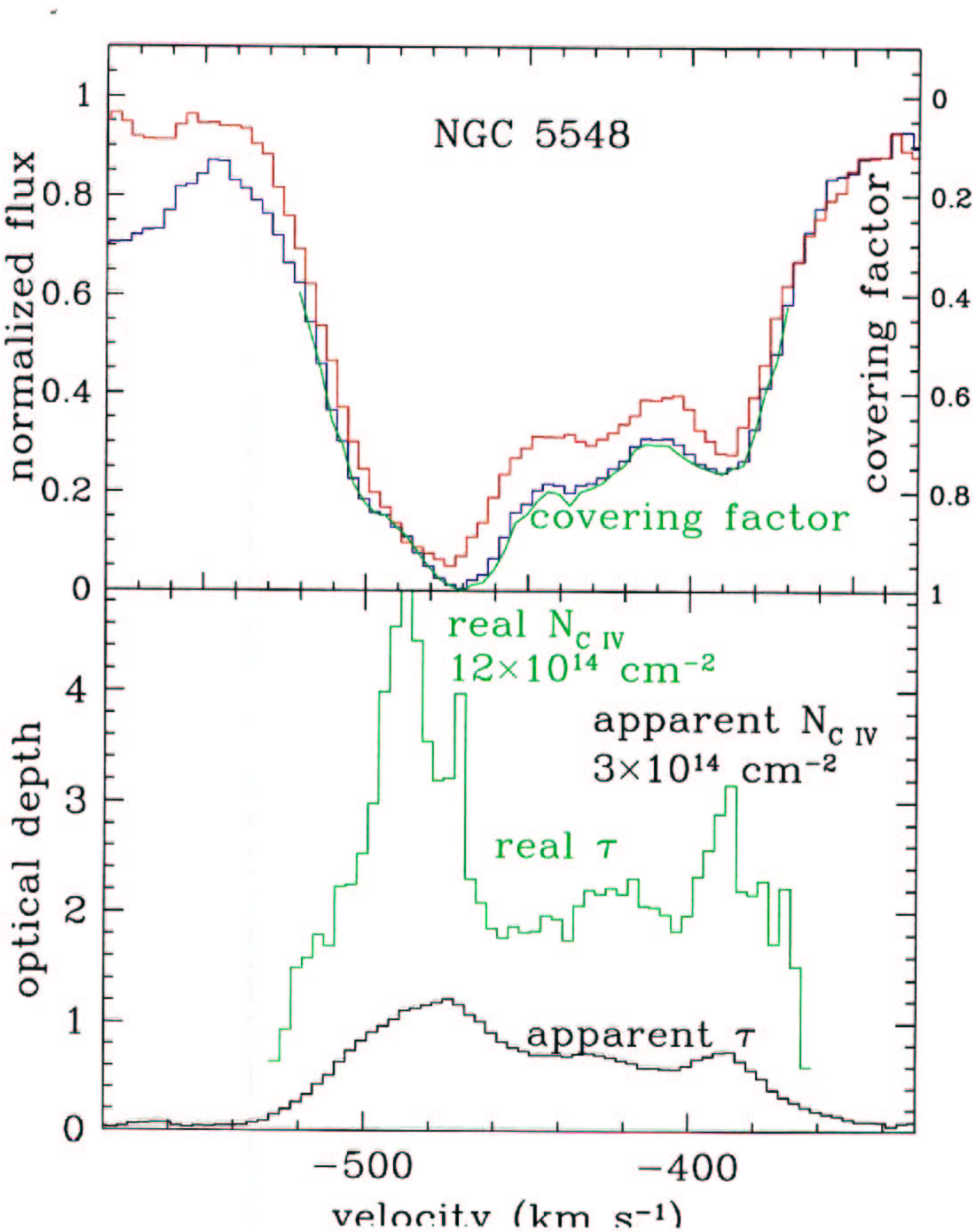
BALQSO 1603+3002
rest wavelength
QSO 1603+3002
z=2.030
observed wavelength
flux (in 10-16 ergs/s/cm2/A)

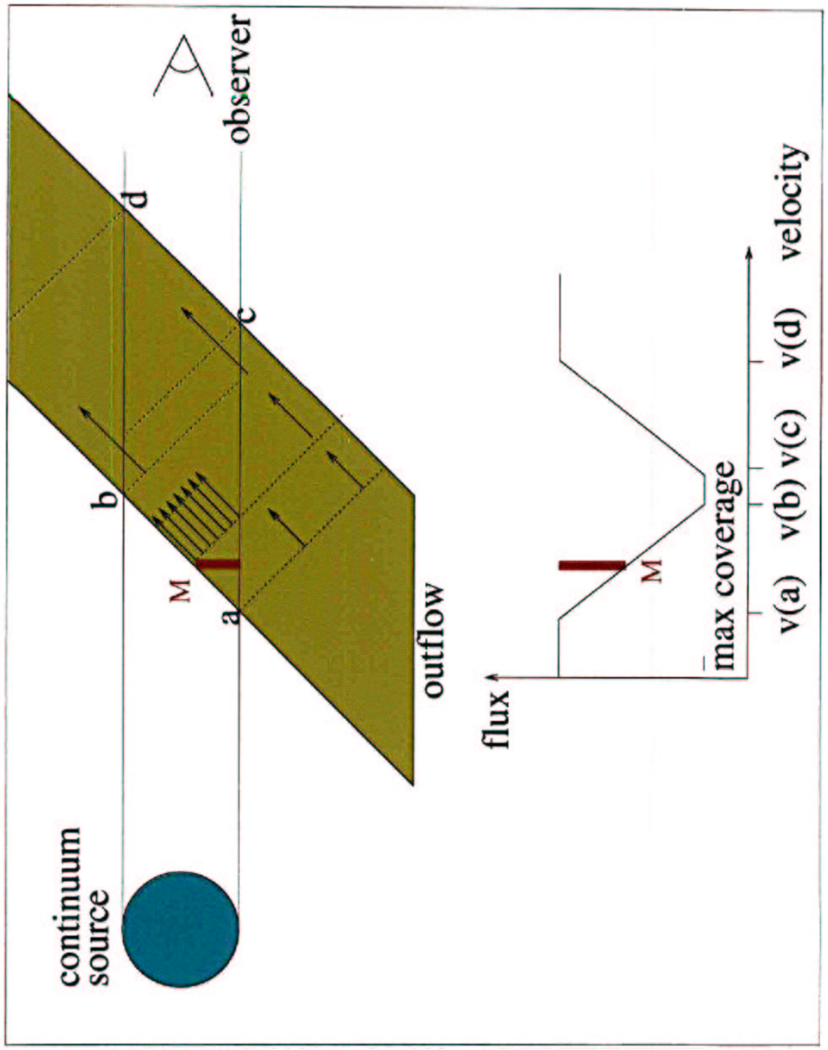

QSO 1603+3002
z=2.030
observed wavelength
4180
4200
4220
4240
Si IV BAL
A blue
A red
velocity (km s^{-1})
−4000
−2000
0
1
0.5
0

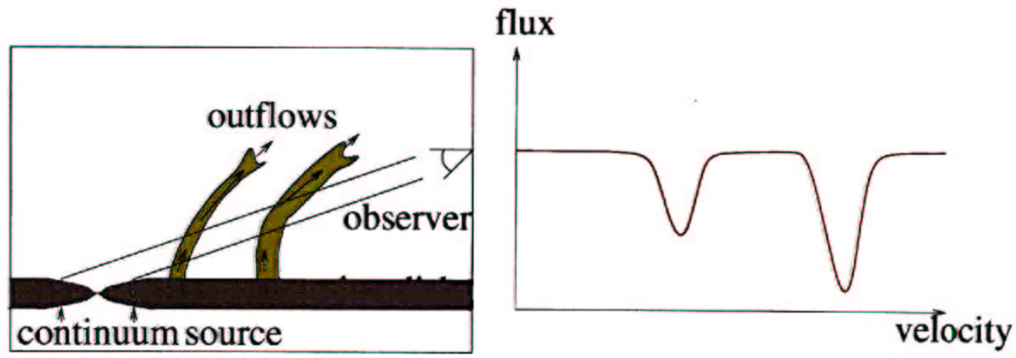

QSO 1603+3002
covering factor
velocity (km s^{-1})
0
0.2
0.4
0.6
0.8
1


QSO 1603+3002
covering factor
velocity (km s⁻¹)


QSO 1603+3002
normalized flux
covering factor
optical depth
real τ
apparent τ
velocity (km s⁻¹)


NGC 5548
normalized flux
covering factor
covering factor
real $N_{C\ IV}$
12×10^{14} cm^{-2}
apparent $N_{C\ IV}$
3×10^{14} cm^{-2}
real τ
apparent τ
optical depth
−500
−400
velocity (km s^{-1})


observer
continuum source
outflow
flux
velocity
max coverage
v(a) v(b) v(c) v(d)
a
b
c
d
M



Paradigm Shift

- We cannot trust apparent optical depth, EW or Gaussian modeling when dealing with intrinsic AGN absorbers.

- Our conceptual picture of the absorbing medium has to shift from Gaussian clouds to dynamical outflows.

- We have to reexamine N_H and U in **all** the available data.

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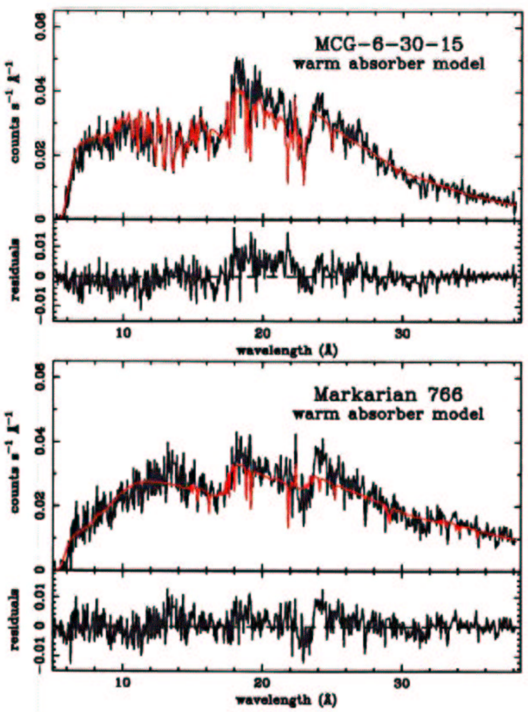


Fig. 4.— Best-fit dusty warm absorber model for MCG−6-30-15 (top) and Mrk 766 (bottom). Broad residuals are seen in both spectra, and cannot be explained by any absorption features.

– 40 –

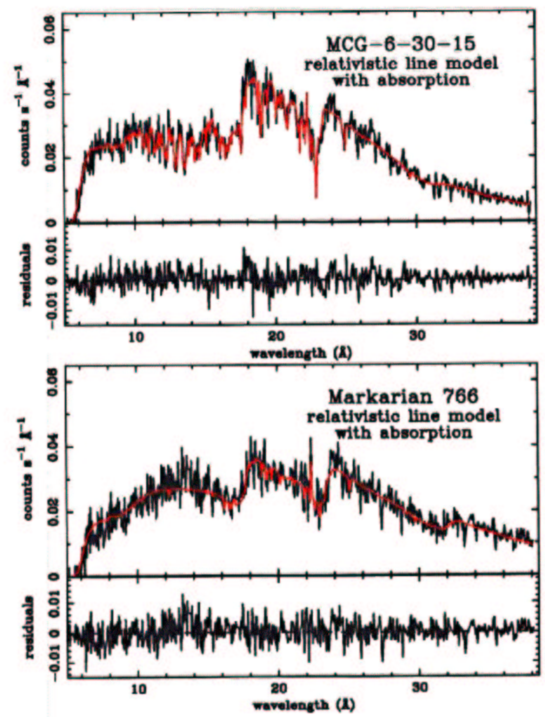


Fig. 12.— Best-fit relativistic line models for MCG−6-30-15 (top) and Mrk 766 (bottom). No obvious residuals remain.

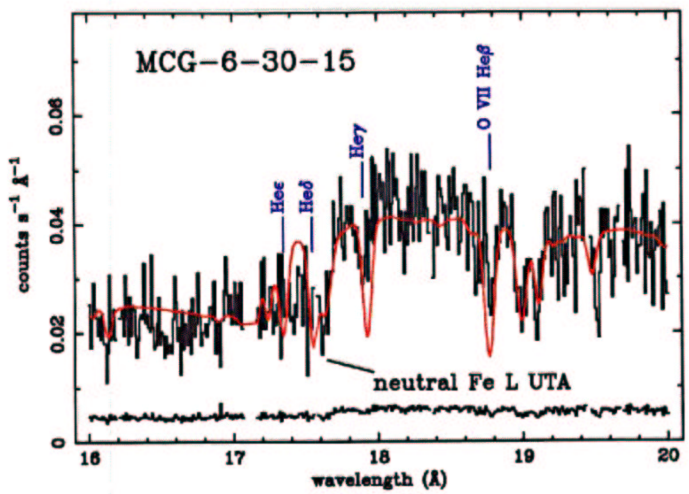


Fig. 11.— The 16 – 20 Å region of the MCG–6-30-15 spectrum showing the higher series lines of O VII and the neutral Fe L UTA using the Lee et al. (2001) dusty warm absorber model, with a reduced neutral Fe L column density ($N_{\rm Fe} = 7 \times 10^{16}$ cm^{-2}). The absorption line equivalent widths of O VII are severely overpredicted compared to the data. In addition, line equivalent widths of O VII are severely overpredicted compared to the data. In addition, the model flux between the Heδ and Heε lines is overpredicted owing to the lack of O VII and Fe L opacity in this spectral region.

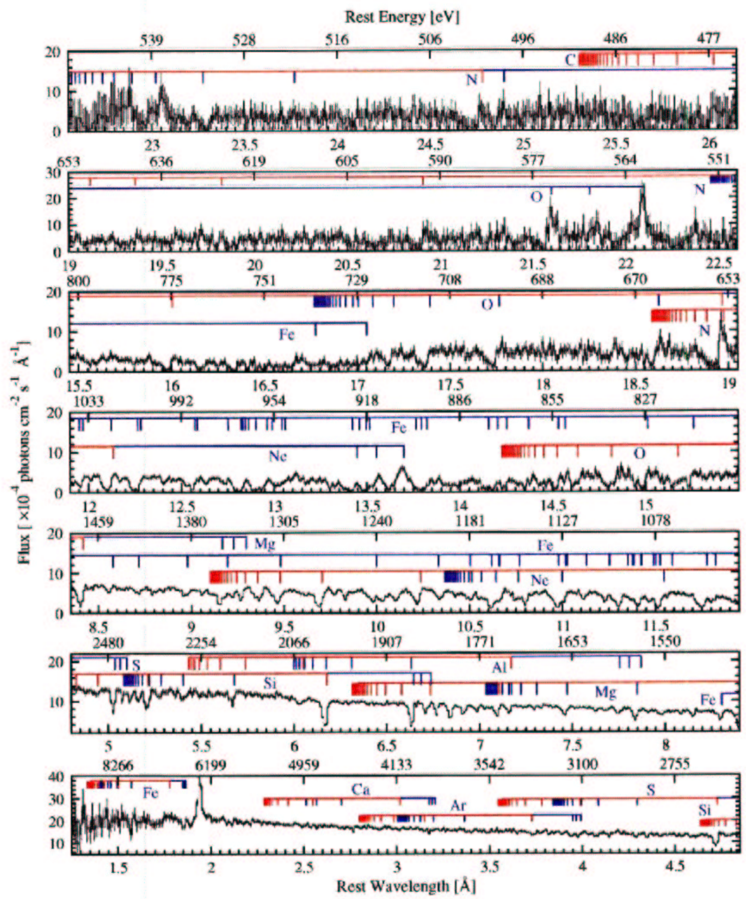
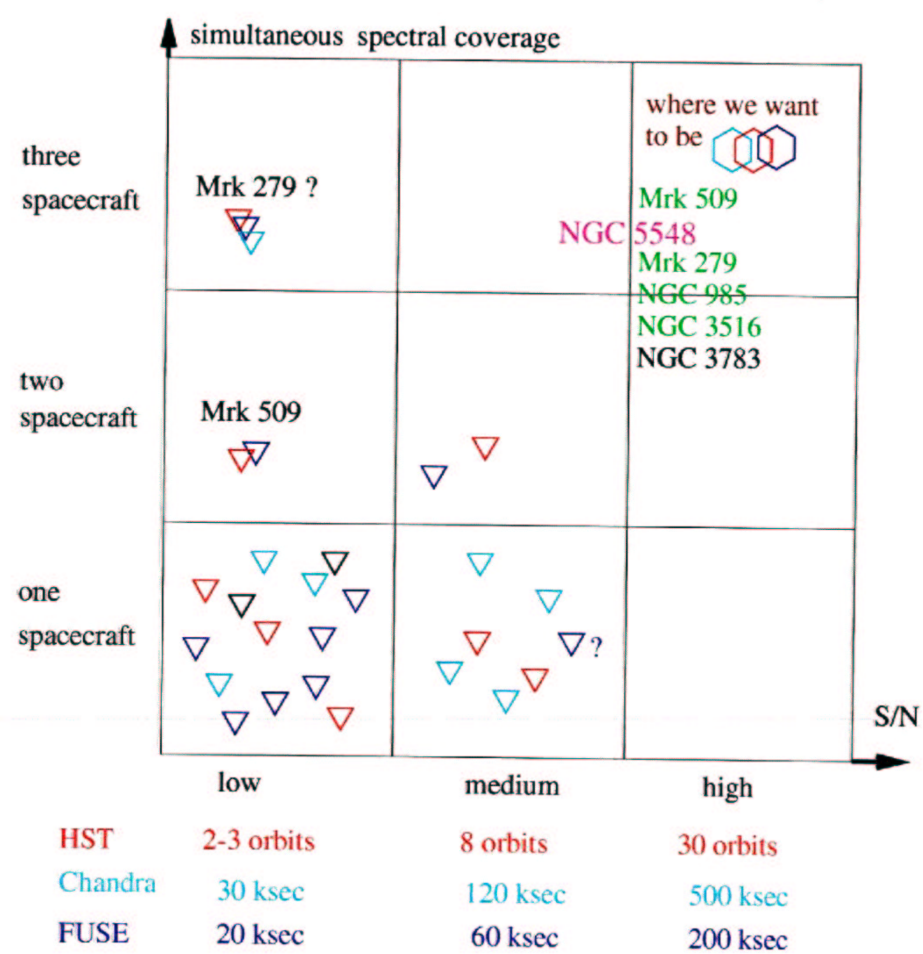


Figure 1. Combined MEG and HEG 900 ks spectrum binned to 0.01 Å. Each data point has an error bar representing its uncertainty. The H-like and He-like lines of the identified ions are marked in red and blue, respectively. For each ion the theoretically expected lines are plotted up to the ion's edge (not all lines are identified in the data). The ions' lines are marked at their expected wavelength in the rest frame of NGC3783, and the blueshift of the absorption lines is noticeable.

Observational Ramifications

- HST: Two Doublets,
  - N V and C IV doublets: (1000 km $s^{-1}$and 500 km s^{-1})
  - Lyα: No hope on its own; Si IV is seen in less than half of the objects.
- FUSE: The Lyman Series,
  - The Lyman series Lyβ λ1025.7, Lyγ λ972.5, Lyδ λ949.7
  - C III λ977.0, N III λ990 (540 km s^{-1}); O VI heavily saturated.
- Chandra and XMM: The Advantage of Line Series,
  - Several hydrogen and helium like ions; EW can be used!



Future Directions

- Instruments: +COS, –FUSE, Constellation X, Mega-X

- Crucial issues to address:
  The relationship between the UV and X-ray warm absorbers
  Distance and column density → $\dot{m}, \dot{E}_k$.

- To extract the physics, a major UV/X-ray campaign is needed.

Summary

- High resolution spectroscopy is revolutionizing the study of AGN outflows

- Conceptual shift: Gaussian clouds → dynamical outflows.

- Crucial issue: The relationship between the UV and X-ray warm absorbers

- To extract the physics, a major UV/X-ray campaign is needed.